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Drip Irrigation, an Adaptive Strategy

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Table of Contents

Abstract

Adaptation has always played a role in the survival of man. In today's Southwest we are quickly approaching a water shortage. Agriculture is the second largest user of water. One way to save water is by conservation. Drip irrigation would save vast amounts of water currently lost to inefficiency. Drip irrigation will become an option in the adaptation in agriculture.

Introduction

Cultural adaptation happens in all cultures. It is a mechanism used to keep a culture from becoming extinct. Adaptation may be as simple as eating a different plant to stave off hunger or as complex as creating a story to explain creation and thus establishing a religion. In the barest sense of the word, adaptation is any adjustment to one's environment. Humans have always used adaptation techniques to survive. People did not appear on Earth knowing everything they could eat. At some point, they had to try eating something they had not eaten before. It might have been a piece of leaf or an ant. This variation in the normal diet, by trying something new, was an adaptation to the diet. Obviously, something that did not upset their stomach or kill them was remembered and eaten when they could obtain it. Over time, hundreds of small adaptations would leave people very different from the first people who made the first adaptation. Today, people on Earth live in a very complex world. Often technology or a new invention becomes an adaptation technique. Irrigation in agriculture is where adaptation is indeed, often tied to technology. To see adaptation in irrigation technology, it is necessary to examine the development of irrigation practices on which our present agricultural industry depends.

Today, adaptation of water-usage practices in the Southwest is essential. Surface water and groundwater withdrawals for farm irrigation in the western seventeen states constitutes about 85 percent of the region's developed supplies. Applying conservation techniques to the largest use of water in the West can ensure water choice alternatives for our future. Drip or trickle irrigation is a promising conservation technique available to agriculturists interested in maintaining or increasing their current production rates while reducing water consumption.

History of Agriculture in the West

Agriculture probably first arose when population outgrew the carrying capacity of the hunting and gathering way of life. Hunter gatherer societies stored food in rockshelters, hundreds of years ago. Information about the food resources of Archaic groups in the Southwest is available from organic material preserved in rockshelter sites and, indirectly from the locations of open sites (Cordell, 1984) By about 1000 B.C., the Archaic people were using a limited amount of corn in their diets. By A.D. 900, agriculture had spread throughout the Southwest. Corn and squash are known primarily from cave sites where the microbotanical remains have been preserved. There is also some evidence of corn, in the form of pollen, from caves and open late Archaic sites. Although the dating of this early corn is not precise, its adoption into an Archaic way of life is undeniable.

The earliest Southwest crops-corn, beans, and many bottle gourds including squash, were domesticated in Mesoamerica between about 7000 and 3000 B.C. (Cordell, 1984) Their appearance in the Southwest is not until Archaic times, about 1000 B.C. for corn, about 300-500 B.C. for squash and beans (Cordell, 1984) Crops were planted usually in areas above 6500 ft, where precipitation is sufficient without irrigation (Cordell, 1984) In some areas, domestic crops provided the majority of the people's food requirements, and a considerable amount of labor was invested to insure agricultural success. Various devices were constructed to divert water to fields, to conserve moisture, and to slow erosion.

The kinds and combinations of features associated with agriculture are diverse. Some of these features and systems include fieldhouses, bordered gardens, check dams, contour terraces, canals, headgates, diversion dams, and ditches. Canals, ditches, headgates, and diversion dams are used to move water from one place to another. They are part of irrigation systems. Canals, designed to carry water, are wide, deep channels cut into the ground designed to carry water. Ditches are shallower versions of canals, function the same as canals and are usually associated with canals. Diversion dams are usually made of earth or stone and are used to temporarily impound water, restricting and directing its flow into a canal or ditch. Reservoirs can be either entirely man-made or incorporate natural depressions to hold water. Reservoirs, however, seem to have been used more to store water for domestic use than for irrigation purposes.

Agricultural features are difficult to date, and so the proximity of a feature to a site is often used as a rough indication of the age of the agricultural feature. These agricultural features appear in many places across the Southwest. Point of Pines, in mountainous eastern Arizona, has a frost-free period of 165-170 days a year and a mean precipitation of 18-20 inches per year. Field systems of terraces follow the contours of the slopes. Their primary function seems to be soil and moisture conservation. Gu Achi, near Santa Rosa, Arizona is very arid with less than 6 inches of rain a year. Brush diversion dams and ditches, low brush dikes, embankments, and small ditches are used to aid in farming. The farming in Gu Achi is dependent on rainfall and runoff, with no permanent water source from which to irrigate. In Chaco Canyon, the environment is not favorable for agriculture. Soil is silty alluvium and rainfall is less than 8 inches a year, most of which falls in summer. There are contour terraces and check dams in Chaco Canyon, but the most prevalent prehistoric water control systems consist of a combination of dams, canals, ditches, headgates, and earth-bordered gardens (Cordell, 1984) They were designed to capture runoff water from the cliff tops and to divert it to fields and bordered gardens on the canyon floor.

By the beginning of the Christian era, the Hohokam, of present day Arizona, were diverting water from the rivers of the Gila system to spots where its life-giving power would be productive (Lavender, 1980). The ditches grew until by A.D. 600 some were as much as thirty feet wide at the top, fifteen feet deep, and carried water to fields six to seven miles from their intake points (Lavender, 1980). Without the aid of metal picks or shovels or wheels for moving carts, the Hohokam excavated networks of canals aggregating as much as 150 miles in length. The job was so well done that during the 1860's Anglo pioneers simply repaired and cleaned the old canals and used them to water their own "pioneering" fields. Even today Pima Indians use sections of the old complex for irrigating their crops (Lavender, 1980).

The early Spanish missionaries brought knowledge of irrigation from their Mediterranean homes. Irrigation was also practiced by trappers, miners, and frontiersmen in many places in the West, although no effort was made to develop an agricultural economy based on irrigation until the Mormon pioneers entered Salt Lake Valley in July, 1847 (Israelsen, 1962). Under the Mormons, irrigation was a cooperative undertaking, with communities being located on the streams issuing from the mountains. Community ditches were constructed to serve both agricultural areas and garden plots in the towns (Israelsen and Hansen 1962). When European settlers moved into the region they brought their own crop plants with them and, for the most part ignored the potential offered by native plants used by the indigenous population. This usage of domesticated European plants in the climatically different west, helped to spur the technological development of irrigation in the United States.

Irrigation in the Great Plains and West

As late as the turn of the nineteenth century, farmers and scientists alike considered the Great Plains and the West as nonirrigable land because irrigation was restricted to areas near streams and reservoirs. This belief changed when water became obtainable from water sources through a variety of pumping techniques.

Flood Irrigation

During the 1930s, most of the farmers who drew water from river sources used the technique known as "wild flooding," to irrigate their crops. This method involved opening the bank of an irrigation ditch to let a thin sheet of water spread across the field. Flooding required reasonably level land so the entire surface could be wetted with the water. For land that had a rough surface or a considerable slope, contour ditches worked best. These small irrigation ditches carried water to the fields on a contoured grade. By blocking or checking the water at various locations, it would overflow the ditch and spread across the field. Because flooding eroded the soil, farmers used this technique primarily on closely growing crops such as alfalfa, sweet clover and small grains.

By the 1950s, farmers primarily used furrow rather than flooding techniques in irrigation. This irrigation method utilized a gated pipe or ditch that ran along the upper edge of a field. Deep furrows that ran at right angles or on the contour to the pipe or head ditch carried water between the plants. Siphon tubes sucked water from the head ditch into the furrows. If a farmer used gated pipe instead of a ditch, the holes or gates in the pipe enabled the water to pour into the furrows. The intake rate of the soil, the amount of water applied, and the slope of the land determined the length of the furrows and the size of the irrigated field (Hurt, 1992). Low absorption rates, for example, enable the furrows to stretch for a quarter mile or more across the land. This irrigation technique did not require the land to be perfectly level, because the water only traveled down the furrows. It did not spread uniformly across a field. Although farmers sometimes had difficulty getting a consistent amount of water to flow in the furrows, the water penetrated the soil slowly, and it provided an excellent way to irrigate the crop (Erhart, et al. 1955).

Western farmers also used a border irrigation method. It involved laying the land out in strips that were level across but which sloped away at a 1-percent grade from the head ditch to the end of the field. This method required graded borders or dikes that ran down the outer edge of a field. Level border irrigation resembled the graded border technique except that the field was level both across and from end to end, and it remained closed at the end to prevent loss of water. Level border irrigation enabled uniform flooding of a field, and it became a popular method in the Southwest, especially for alfalfa, small grains, and closely growing crops. This technique enabled quick application and uniform distribution of water (Hurt, 1992).

Pump Irrigation

To overcome the lack of surface water available for agriculture, some farmers during the early twentieth century used windmills to pump ground water into reservoir holding tanks (Hurt, 1992). The impoundment held water pumped from the ground and ensured a consistent flow to the field. Windmills, however were only sufficient for irrigating vegetable gardens and fruit trees, because this technology could not pump a great volume of water. At best a windmill only irrigated several acres, and did not support large-scale irrigation (Hurt, 1992). The high cost of maintenance for windmills also prevented widespread use for irrigation, particularly if a farmer could afford a comparable investment for a pump powered by a gas or steam engine. On the Great Plains, irrigation worked best when pumps lifted the water from the groundwater table and provided a consistent flow of water to the fields. By late nineteenth and early twentieth centuries Western farmers began using centrifugal pumps. These pumps delivered several hundred gallons of water per minute, and this technology enabled farmers to tap ground water supplies with shallow wells, particularly in river valleys. Electric, gas, and steam motors powered these pumps. Because each irrigation pump could cost as much as $400, and the well and power were additional expenses, few farmers could afford the investment. Moreover, the increased profits from pump irrigated crops did not justify the investment.

After 1930, technological change in the form of powerful turbine pumps, moveable sprinklers, and gated pipe enabled farmers to irrigate large tracts of land far removed from traditional water sources. These improvements not only permitted farmers to pump more water from great depths, but the new technology also became increasingly affordable. By the 1930s, a farmer on the Plains needed little more than $2,000 for a well, casing, pump, and engine to mine water from nearly 200 feet beneath the surface (Green, 1973). If a farmer built his well house from lumber already at hand and used an engine from a junked automobile, the investment decreased considerably. To encourage further development, the federal government provided modest help under the Water Facilities Act of 1937 and through the Federal Housing Administration to help farmers develop pump irrigation (Green, 1973). Local banks, irrigation equipment companies, and pump dealers also provided financial support. With all this help, farmers, began to depend on irrigation for maximum production, instead of as crop insurance.

Sprinkler Irrigation

Sprinkler irrigation became popular in the Pacific Northwest about 1930. It involved spraying water over a field with a perforated pipe or nozzle. Farmers in Southern California also adopted sprinkler irrigation in the 1930s. Sprinkler irrigation was preferable to furrow irrigation because farmers lost less water to evaporation as the water was moved from pipe to the fields. In addition, they could better control the amount of water applied to their fields. By the early 1950s, orchard growers throughout the West rapidly shifted from furrow to sprinkler irrigation (McCulloch and Schrunk 1955). The sprinklers were advantageous for land so level the water would not run across the furrow and for land too rough for surface irrigation or too shallow for leveling. And, farmers preferred sprinkler irrigation where the porous soil could not hold surface water, where inadequate stream flow prevented furrow or flooding methods, and where expensive water and labor prevailed. In addition, sprinklers enabled farmers to irrigate land that would otherwise have remained in dryland agricultural crops or pasture. At first, however, high costs, inefficient design, and poor mobility restricted the acceptance of sprinkler systems. Some of these systems, for example, had to be moved by hand. This procedure involved considerable labor to uncouple, move, and reassemble the irrigation pipe. Other systems could be moved by tractors, because the pipe and sprinklers were mounted on skids or wheels or were attached to a moveable boom (Hurt, 1992).

Sprinkler irrigation became increasingly popular, and it spread rapidly. Portable pipes and couplings made it easy to irrigate land previously thought unsuitable for surface irrigation. In 1946, for example, sprinklers irrigated less than 250,000 acres of farmland in the United States, but by 1954 farmers irrigated an estimated three million acres with this method (McCulloch and Schrunk 1955). With sprinkler irrigation expanding at an estimated rate of 500,000 acres annually by the mid-fifties, adequate water supply and cost became the primary limiting factors for adoption. Previously, availability of farmland had been the limiting factor.

The center-pivot sprinkler eliminated most irrigation labor problems. Invented by Frank Zybach, a farmer in eastern Colorado, and patented in 1952, the system consisted of sprinklers mounted on a six-inch pipe supported by a row of moveable towers (Splinter, 1976). Water entered the pipe from the center of the field and propelled the system in a continuous circle. The sprinklers applied increasing amounts of water away from the well to insure a uniform application of water across the field as the system revolved. Because the pipe is at least eight feet above the ground, only the narrow wheels interfered with the growing crops. The center-pivot sprinkler not only allowed the farmer to automatically irrigate, but could also apply liquid fertilizer with the water. Most center-pivot systems cover 133 of a 160 acre field every three or four days and apply one inch of water per revolution (Deering, 1969). Special adapters can be added to swing out and cover the corners of the quarter section in order to irrigate nearly the entire 160 acres. The largest systems irrigate a section or 640 acres. These big pivot systems require one-half mile of eight-inch pipe and twenty towers to support the pipe and sprinklers (Splinter, 1976).

Center pivot sprinklers were slow to catch on with farmers due to the cost, but changed irrigation from a labor intensive to a labor extensive agricultural practice because more acres could be irrigated with less work than ever before. Although center-pivot sprinklers were slow to catch on, by the late 1960's many farmers had invested in them and by 1973 center-pivot systems irrigated 400,000 acres, nearly a four-fold increase since 1955 (Herpich, 1971).

Farmers throughout the Great Plains and the West know that water is a commodity which is becoming increasingly valuable as water tables drop and urban area water demand increases. Having well water to depend on when drought hits is, essentially, crop insurance. Often it is the difference between crop success and crop failure. This increased chance of a successful crops means more income to farmers, and more revenue to the states. In 1966, for example, irrigation farmers in Kansas increased their income about $33 for each acre-foot of water applied to their fields. Two years later, economists estimated the state received at least $10 for every acre-foot of water used and that farm income increased about $26 million because of irrigation (Hurt, 1992). Moreover, a 1968 survey of four counties in southwestern Kansas indicated the price paid for irrigated land averaged $121 compared to $80 per acre for dryland. In 1976, the price of irrigated land averaged $740 compared to $476 for nonirrigated land and $264 per acre for ranch land. By the late 1970s, a farmer in Kansas could expect to invest between $30,000 and $50,000 for wells and pumps. Many still made the investment and switched to sprinkler irrigation (Hurt, 1992). By 1987, irrigated land , like other agricultural land did decline in value, averaging $549 per acre, compared to $404 per acre for dryland (Hurt, 1992).

Benefits of Drip Irrigation for the Future

An entirely new agricultural technology, trickle or drip irrigation, was developed in the early 1960's. Initial progress was sporadic even though the advantages in water management with trickle systems were recognized. In the mid 1950's, a small irrigation manufacturing firm in New York began supplying polyethylene tubing to water plants and flowers grown in green houses (Nakayama, 1986). By the early 1960's, plastic pipe trickle irrigation systems were extensively used in greenhouse research and most commercial greenhouse enterprises. S. Davis installed the first field experiment with a subsurface trickle irrigation system on a lemon orchard at Pomona, California in 1962, and on oranges near Riverside, California in 1964 (Nakayama, 1986). With the sucess stories of surface drip irrigation coming from Israel, D. Gustafson visited Israel in 1968, and returned to install the first research and demonstration study on trees on a private grower's avocado orchard in San Diego, California, in 1969. About the same time, B. Hall began to conduct trials using surface trickle irrigation on strawberries and tomatoes along with plastic mulches, also in and around San Diego. From 1968 through the early 1970's, numerous inventors and companies began to develop trickle irrigation emitters that totaled well over 250 devices before the mid 1970's (Nakayama, 1986). Extensive research and development has isolated the main problems and solutions were developed to make systems more reliable. Today, drip or trickle irrigation is becoming increasingly popular.

Drip irrigation refers to several types of low-volume irrigation systems, including drip, trickle, spitters and, microsprinklers. Drip irrigation is used in the United States most prevalently in Southwestern gardens and landscaping.

In many countries, the agricultural sector is facing increased competition from the growing industrial and urban sectors for a share of a relatively fixed supply of water (Caswell, 1989). At the same time, an expanded agricultural sector is needed to feed a burgeoning population. Irrigation has never been more important to feeding a world of people than it is today. The importance of irrigation in the world today is well stated by N. D. Gulhati of India: *Irrigation in many countries is an old art-as old as civilization-but for the whole world it is a modern science-the science of survival.* Increased competition for surface water supplies has led to faster extractions from groundwater basins. When the volume of water pumped out of the ground exceeds the recharge time, the water table lowers. Those who drill for water have to drill deeper, build longer pipe, and stronger pumps to bring the water to the surface. Dropping water tables have resulted in steadily increasing well and pump costs. Paired with a growing, water demanding population, adequate groundwater supplies are therefore becoming more expensive. Water conservation is one of many ways to ease our increasing water shortage (Caswell, 1989).

Drip irrigation technology has several advantages over surface irrigation techniques. By 1990, some irrigation farmers in California and Arizona had cut their water use in half while doubling their yields and lowering their energy consumption by using underground drip irrigation. Drip provides precise water control. Every part of a drip irrigation system is constructed with an exact flow rate so every outlet can be controlled to release the amount of water desired, down to the ounce (Kourik, 1993). Although few farmers have been interested in subsurface technology, it uses less water. There are other benefits to drip irrigation systems: the chemigation (fertilizer and pesticide injection) is more efficient and labor costs are lower due to more uniform plant development and fewer weeds (Caswell, 1989). Applying a dissolved or liquid fertilizer to the drip water system delivers it more efficiently to the roots. Subsurface irrigation also retards weed growth between rows because water is applied only to the root system. Plant response to trickling is generally better than to other methods of irrigation. This is easily understandable in view of the fact that trickling irrigation maitains optimum soil moisture status. In addition, the emitters make only a small moist spot, while larger areas between emitters remain too dry in dry summer climates for weeds to sprout (Kourik, 1993).

Salinity of irrigation water is less harmful than previously thought when the original soil concentration is tolerable to the plants. The high frequency of trickling usually maintains the concentration of the soil solution on an acceptable level (Balogh, 1985). In the case of saline or alkaline soils and good irrigation water the same possibility is given. Only the coincidence of saline soils with saline water should be avoided in drip irrigation. The salinity problem can be corrected with occasional rainfall or an occasional overwatering with the drip system to leach the salinity downward into the soil.

Experiments indicate that productivity increases with subsurface irrigation. Tomatoes increased from 26 to 100 tons per acre while cotton jumped from 930 to 1,600 pounds per acre. On an experimental plot with underground drip in 1984, 18 inches of water was used to produce 6,900 pounds of wheat. Normal water use for a wheat crop alone is 30 to 36 inches (Wickersham 1984). The drip system saved half the water normally used, saving the farmer half his money spent on water.

On the other hand there are several serious problems associated with drip or trickle irrigation in agriculture. Arable crops of dense vegetation may be difficult to irrigate by trickling. Even watering of vegetables and other row crops by trickling equipment can be more expensive than with other methods, because of the seasonal necessity of removing the lateral piping. This necessity increases operation and maintenance expenses significantly (Balogh, 1985).

Irrigation water processing is almost unavoidable due to the size of the emitters. Small suspended particles such as sand or silt or materials such as iron or lime in the irrigation water may obstruct water delivery to the plants. Filtration and sometimes more complicated water cleaning devices must be inserted into the water transporting and distributing pipe network to prevent clogging. Water cleaning is always a cheaper and easier procedure than the detection and repair or removal of clogged emitters (Balogh, 1985).

Build up of salinity also occurs with trickling irrigation, as all irrigation water contains dissolved salts. These salts accumulate at the edges of the wetted soil of the root zone. By sometimes applying significantly more water then the plants consume, most of the salts can be pushed or leached down out of the root zone (Balogh, 1985).

Drip or trickle irrigation has been used in the United States for almost 30 years. One hundred eighty-five thousand hectares of drip irrigated land already exist in the United States, but this represents only 2% of the total irrigated land in the country (Caswell, 1989). In the United States, the states of California, Florida, Georgia, Hawaii, Michigan, and Texas account for over 85 percent of the trickle irrigated acreage in 1982 (Nakayama, 1986). Although the area under trickle irrigation is presently small compared to the total irrigated area, higher valued crops and land are being utilized. The list of trickle irrigated agricultural crops includes avocado, grape, citrus, strawberry, tomato, potato, sugarcane, cotton, cabbage, tea and others (Irealsen, 1962).

Economic Considerations in Drip Irrigation

Trickle irrigation and center pivot systems are more expensive to install and maintain, and require better management skills and farming pratices than conventional sprinklers or furrows. In 1985, installing drip irrigation cost on the average about $600 to $1400 per acre, for a complete system including pumps, computer monitoring systems, and hardware (Nakayama, 1986). Today, installation costs have risen because of inflation in the 1980's. Installation on a 160 acre field can total $300,000 or more and is often contracted out to a company specializing in drip irrigation. New center-pivot systems, because they deliver so efficiently, can cut operating costs by a quarter over old furrow systems, but they also cost as much as $80,000, or $500 per acre, to install on a 160 acre field (Cook, 1991).

Subsurface irrigation maintainance costs farmers in the United States $20 to $80 per acre annually, depending on the climate and other factors. Pipe and emitters need to be replaced every 8-10 years, but the main computer and monitoring system can be reusable for many more years. Yearly maintenance for a 160 acre field therefore ranges from $3,200 to $12,800. After comparing the drip irrigation upkeep with the average $55 per acre furrow irrigation upkeep, totaling $8,800, it is understandable that farmers prefer the least expensive method (Hurt, 1992). Drip irrigation can be a substantially increased investment over sprinklers or furrow irrigation even before water and energy are purchased.

Those involved in drip irrigation stress that its economic feasibilty depends not only on the savings from using less water and energy, but also from producing higher yields. Return risk analysis by economists suggests that without multiple cropping on the fields, drip and trickle irrigation is a losing venture (Prevatt 1992). This means a farmer cannot really afford to install either the center-pivot sprinklers or drip irrigation unless it increases his crop production enough to pay for the machinery, equipment, and maintainance. Without other incentives, growers will not adopt drip irigation systems. If it were possible, selling water rights from the saved water could help farmers offset the initial investment and the continuing maintenance costs of the more efficient sprinklers or drip systems.

Most federal water is controlled by the Department of the Interior's Bureau of Reclamation, which was set up in 1902 to build the 600 dams and 53,000 miles of canals that now irrigate the American West (Spencer, 1992). While the farmers received rights to water, they were never granted the right to transfer their water rights. That crucial power remained with the Bureau of Reclamation, which works closely with the local water companies.

A lot of Colorado River water, for example, goes to farmers in southern California's Imperial Valley, who pay around $10 an acre-foot to use it (Spencer, 1992). But these farmers do not contract with the Bureau themselves. The Imperial Irrigation District owns the water rights. The farmers can use the water, but they cannot sell it, any more than any city dweller can sell the water coming out of his tap.

As economic value of water has escalated in recent years, the Bureau of Reclamation has struggled to hold onto its power and privileges, thereby effectively undermining the development of a functioning market for water. Some examples:

1. No transfer of rights can take place without the Bureau's approval. The approval process often forbids a water user from making a profit from the sale of the water. Even if the farmers were willing to lease their water rights to others, the Bureau would apply the stipulation that no profit can be made from the sale, thus providing little incentive to lease

Conclusions

Adaptation has always been part of mankind's survival on Earth. In irrigated agriculture, the land is modified to direct water where it is needed to sustain life in plants. Today we use the technology of hundreds of years of irrigation knowledge in our own quest for survival. But, the technology of the past alone is not sufficient for the survival of growing populations of the future. We must learn to conserve water, the most precious resource known to us. Drip irrigation applied to agriculture can save thousands of wasted acre feet of water, while producing as much product as conventional irrigation methods without the cost of creating artificial environments. The time has come for improved irrigation techniques to be applied in agriculture. It is merely one more step necessary in the adaptation of mankind, who is overpopulating the world.

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